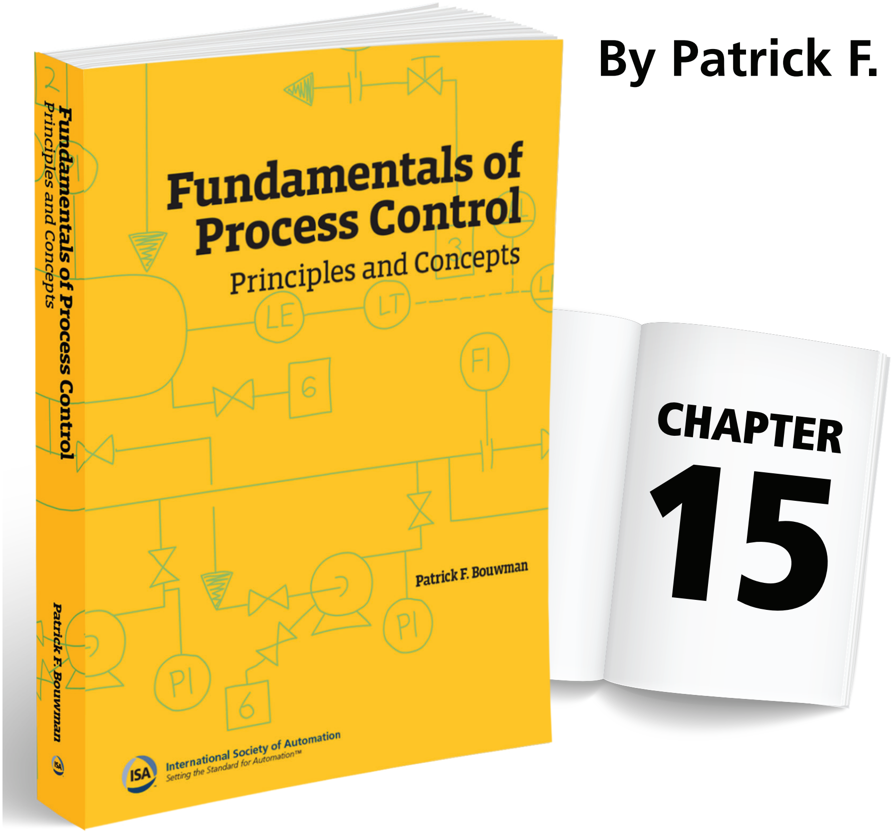
Chapter 15 of:

Fundamentals of Process Control

Patrick F. Bouwman

Fundamentals of Process Control

By Patrick F. Bouwman



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Principles and Concepts

By Patrick F. Bouwman

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15

Special Control Strategies

There are many important variations, extensions, and modifications of the standard control strategies. To illustrate the diversity of possible principles and concepts, this chapter will present several such implementations.

Learning Objectives

- Understand three-element boiler control
- Understand selective control
- Understand override control
- Recognize duplex and split-range control
- Recognize auto-selector or cutback control

15.1 Introduction

As we employ more advanced control strategies, the number of computational requirements increases. These additional computational functions are usually implemented by either specialty controllers or general-purpose controllers, with programmable functions primarily implemented by microprocessors. However, as we consider various control strategies, it is helpful to also consider the signal processing functions that are involved and the specific functions of the various computational operations.

The use of microprocessors extends this list virtually without limit. Complex calculations can be done without an increase in hardware. However, the increase in software development can be complex and expensive to implement and maintain. Previous chapters discussed the use of specialty controllers, such as in feedforward control (Chapter 12) and in multivariable control (Chapter 13). Special signal processing functions have also been introduced in ratio control (Chapter 14). Advanced process control functions are now standard in most programmable logic controllers (PLCs), programmable automation controllers (PACs), and distributed control systems (DCSs). Typical computational components used in process control include the following:

- **Addition/subtraction** – The output signal is the algebraic sum or difference of the input signals.
- **Multiplication/division** – The output signal is produced by multiplying or dividing the input signals.
- **Square root extraction** – The output signal is the square root of the input signal.
- **High/low selector** – The output signal is the highest/lowest of two or more input signals.
- **High/low limiter** – The output signal is the input signal limited to some preset high/low value.
- **Function generator** – The output signal is a function of the input signal.
- **Integrator** – The output signal is the time integral of the input signal. An integrator is also often called a *totalizer.*
- **Linear lag** – The output signal is the solution of a first-order differential equation in which the input signal is the forcing function. This is expressed mathematically as follows:

$$output = \left(\frac{K}{1 + \tau s} \right) input \tag{15-1}$$

where

K = gain
τ = time constant
s = Laplace transform operator d/dt

- **Lead-lag** – The output signal is the solution to the following differential equation. This is expressed mathematically as follows:

$$output = K \left(\frac{1 + \tau_1 s}{1 + \tau_2 s} \right) input \tag{15-2}$$

where

K = gain
τ_1 = time constant 1
τ_2 = time constant 2
s = Laplace transform operator d/dt

A more complete list of such signal processing functions is included in ISA-5.1[1] Table 5.6. These signal processing functions are available both as analog hardware modules and as software in most DCS control packages.

One of the most frequently encountered special control strategies in industry is *three-element boiler control*. This control strategy combines feedback, feedforward, and cascade control to control the water level in a boiler steam drum.

15.2 Three-Element Boiler Control

Steam drums are used extensively throughout process industries and utilities to control the level of boiling water contained in boiler drums in process plants to provide a constant supply of steam. If the water level is too high, flooding of steam purification equipment can occur. If the level is too low, efficiency is reduced and pressure in the drum can build to dangerous levels. A drum-level control system tightly controls the water level no matter what disturbances are present, such as a change in level due to increase or decrease of steam demand or feedwater flow variations. A simplified piping and instrumentation diagram (P&ID) of a classic three-element strategy is shown in Figure 15-1.

Steam flow from the steam drum is measured, and this load on the system is compensated for by using feedforward control. Feedback control on the water level in the drum is handled in the conventional manner, and the manipulated flow into the steam drum (makeup water) is controlled through a cascade arrangement. This general arrangement is feedforward plus feedback plus cascade control, which explains the name *three-element feedwater regulator*. Figure 15-2 shows the block diagram of the strategy, clearly presenting the feedforward, cascade, and feedback control arrangements.

All three types of controls can be implemented using a single three-element regulator as shown in Figure 15-3. This is a classic example of this type of control, and there are literally thousands of these three-element regulators installed. In this arrangement, feedforward control, in effect, is used to provide compensation for significant variations in the major disturbance or the major load on the process. Arrangements such as this are often referred to as *load compensation*.

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[1] ISA-5.1-2009, *Instrumentation Symbols and Identification* (Research Triangle Park, NC: ISA [International Society of Automation]).

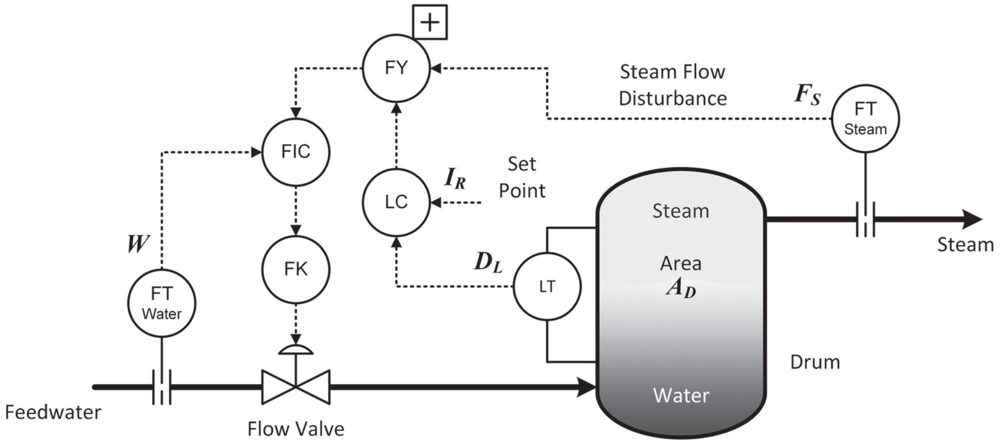


Figure 15-1. Three-element boiler control.

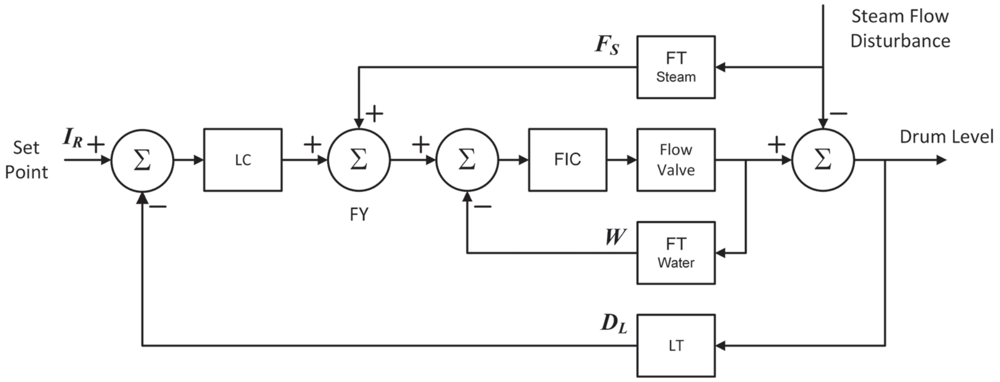


Figure 15-2. Three-element boiler control block diagram.

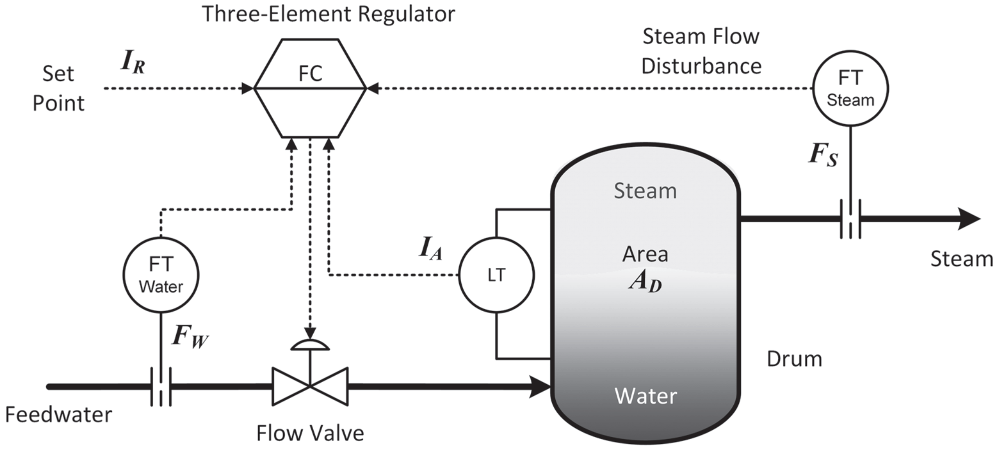


Figure 15-3. Boiler control using a three-element regulator.

15.3 Selective, Override, and Split-Range Control

There are many situations where more than one measured variable is used to control one manipulated variable. Also, some control configurations exist where two or more controllers control one manipulated variable. In both of these configurations, the selection of which measured value or which controller controls the manipulated variable is dictated by some prearranged criteria implemented in control logic.

In selective control applications, the lowest, highest, or median signal from among two or more signals is selected. In most applications, selective control is a form of multivariable control where the selectors dictate the online adjustment of control strategies as a function of changing operating conditions. The selectors enable the control strategies to be changed effectively and without disturbing the process. Override and selective control are usually implemented for safety and optimization considerations. These techniques often deal with multiple control objectives (controlled variables) and a single manipulated variable.

Selective Control

In discussing control loops, each controlled variable in a process must be paired with a specific manipulated variable at any given instant of time. However, because the number of controlled variables and the number of manipulated variables may not always be equal, a logical means of sharing variables among loops must be devised. It may be necessary to switch a controller from one controlled variable to another, or it may be necessary to switch a controller from one manipulated variable to another. Depending on what needs to be selected, this can be done with selective devices that have two or more inputs and produce a single output. The use of such selective devices is a way to achieve constraint control on flows and other operating conditions.

Selecting Measured Variables

A simple low-selector control system is illustrated in Figure 15-4. Characteristic of selective control is that there are multiple inputs to the selector. In this example, temperature is measured at two different locations in the room, but only the lower of the two is directed to the controller. In this example, a second temperature transmitter is placed in the room close to the door. When the door opens and warm air escapes, the temperature close to the door will drop and will be lower than the temperature sensed by the central temperature transmitter. The low selector will select the lower of the two temperatures (TE 2), thereby directing the temperature controller (TIC) to increase fuel to the furnace to compensate for the drop in temperature. This simple strategy will reduce the time constant of the room in returning to a comfortable temperature. Effectively, the dead time of the room has been reduced because the controller reacts to

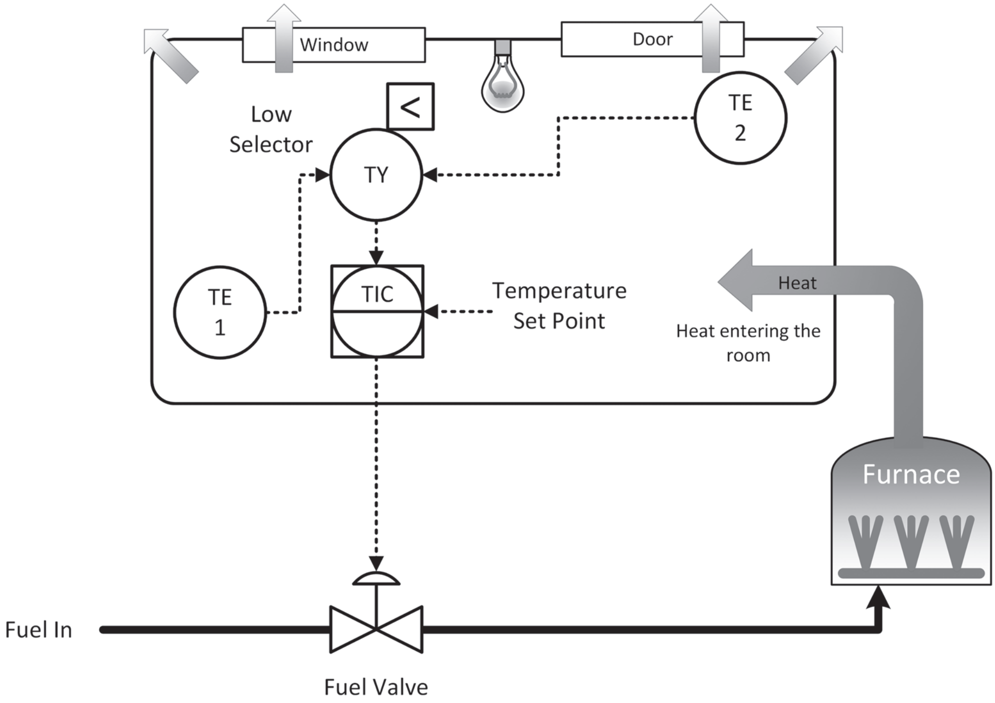


Figure 15-4. Simple low-selector temperature control system.

the temperature at the door (TE 2) immediately instead of having to wait for the room temperature sensor (TE 1) to measure the change in temperature.

This type of selective control is also often referred to as *auto-selector control*, and when the selector relay is a low selector, it is also referred to as *cutback control*.

Selecting Manipulated Variables

In selective control, we use similar types of selecting devices and logic when limits must be placed on one or more controlled variables with a single manipulated variable. In such cases, the controller output is the point at which a selection is made. Refer to Figure 15-5 for a strategy in which pressure is controlled in a pipeline by a throttle valve on a pump discharge whenever the pump motor current is below its rated limit. If the pump motor current should increase to its limit, the current controller (IP) in the pump motor takes over manipulation of the control valve from the pressure controller (PC) and closes the valve further. As a result, pipeline pressure is controlled below the set point on the PC. (This can also be viewed as override control.)

The reset feedback structure in both controllers is provided to eliminate reset (integral action) windup. Without such feedback, the controller action is delayed until the controller reset action unwinds, and the override protection might take effect too late.

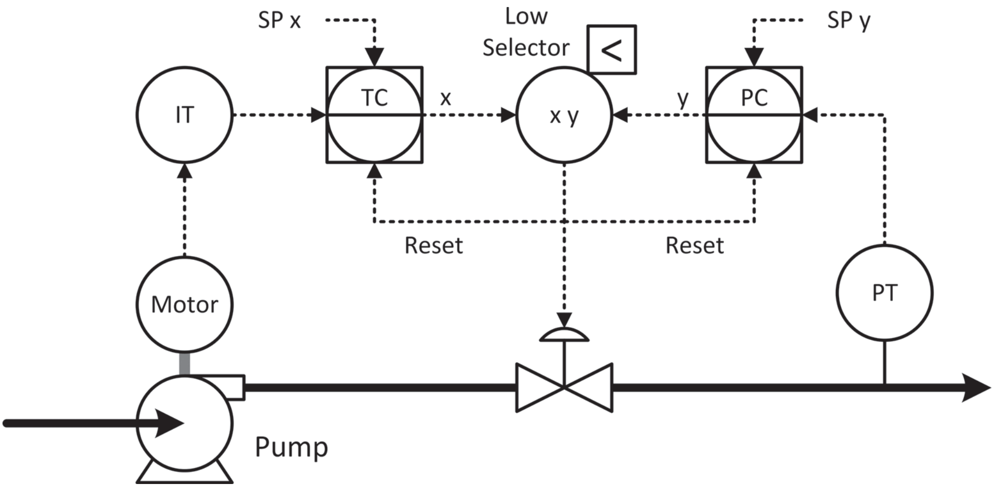


Figure 15-5. Selective control of pressure in a pipeline.

Figure 15-6 illustrates a more complex control strategy that employs many computational functions; the temperature of a process heater is controlled by selecting one of two fuels, the first being of limited availability and less expensive (fuel *A*) and the second being more expensive (fuel *B*). The objective is to use fuel *A* to the limit of its availability before starting to use fuel *B*.

Assume that primary fuel *A* is burned up to the high limit of its availability and is then supplemented with fuel *B*. Fuel *A* has a high limit that is an input to a low selector on the set point of *A* (FY-C). This is shown as a manual input of the high limit, but it could also be provided automatically.

Any difference between the output of the temperature controller and the flow of fuel *A* is converted to a set point signal for fuel *B*. In reality, the temperature controller output represents the total heat input to the system from the two combined fuels. The set point F_A of the flow controller FC-A for fuel *A* is calculated as:

$$F_A = m\left(1 + \frac{B}{A}\right) \tag{15-3}$$

where

F_A = fuel *A* set point (FC-A)
m = temperature controller output (TIC)
A = maximum heat input by fuel *A*
B = maximum heat input by fuel *B*

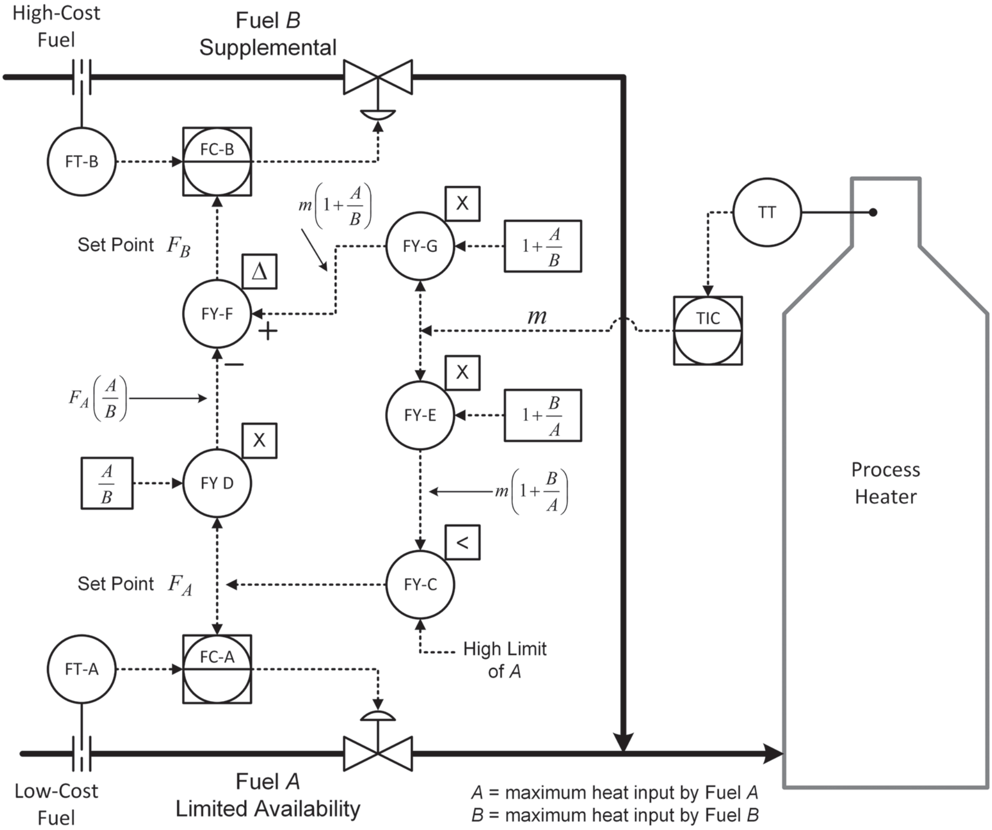


Figure 15-6. Selective control of two manipulated variables and one controlled variable.

The ratio B/A represents the full-scale heat input that can be generated by fuel B to that of fuel A. The temperature controller output (m) represents the total heat input requirement of the system, which has to be met by the two fuels. Through this correction, the controller output (m) and the fuel A set point (F_A) will be on the same scale.

These computations are needed to ensure a smooth transition between the two modes of operation. The fuel B set point (F_B) is calculated by converting the output (m) of the temperature controller (TIC) and the equivalent flow of fuel A into a set-point signal for the supplemental fuel flow controller (FIC-B). The set point for fuel B is then calculated as:

$$F_B = m\left(1+\frac{A}{B}\right) - F_A\left(\frac{A}{B}\right)$$

then

$$F_B = m\left(1+\frac{A}{B}\right) - m\left(1+\frac{B}{A}\right)\left(\frac{A}{B}\right) \tag{15-4}$$

As long as the requirement for fuel *A* is at or below the high limit set by FY-C, the two inputs to the subtracting function (FY-F) will cancel one another, meaning that fuel *B* is not being used and the *B* set point will be zero:

$$m\left(1+\frac{A}{B}\right)-m\left(1+\frac{B}{A}\right)\left(\frac{A}{B}\right)=0$$

When the high limit of fuel *A* is exceeded, F_A becomes constant and F_B starts to increase.

Any difference between the output of the temperature controller and the flow of fuel *A* is converted to a set point signal for fuel *B*.

Override Control

Override control is often considered as a special type of selective control. The override control concept is a strategy by which a process variable is kept within a confined limit, usually for protective purposes. (*Interlock control* is an alternate protective method, but it is usually oriented toward equipment malfunction, and it acts to shut down the process. Override control is less drastic.) Override control maintains the process in operation but within and under safe confined conditions.

Surge Tank Example

To illustrate override control, consider the flow control from the surge tank shown in Figure 15-7. A hot saturated liquid enters a process surge tank, then it is pumped into the process. Normally, the surge tank operates at a normal safe level as shown, but if the level gets too low, the liquid will not have enough net positive suction head (NPSH) and the pump will start to cavitate. Override control provides the required protection to the pump. The strategy for providing this protection is shown in Figure 15-8.

In the override control application shown in Figure 15-8, the tank level is now controlled. The variable-speed pump will, of course, pump more liquid as the energy input to it increases. It follows that the flow controller must, therefore, be a reverse-acting controller (output increases as input decreases), and the level controller must be a direct-acting (output increases as input increases) controller. The output of each controller is connected to a low-level selector relay, and its output goes to the pump.

Under normal operating conditions, the level set point is above the normal surge tank level, and the level controller will attempt to speed up the pump. Normally, the output of the flow controller will be less, and the low-level selector relay will select the flow controller output to manipulate pump speed. If the flow of hot, saturated liquid

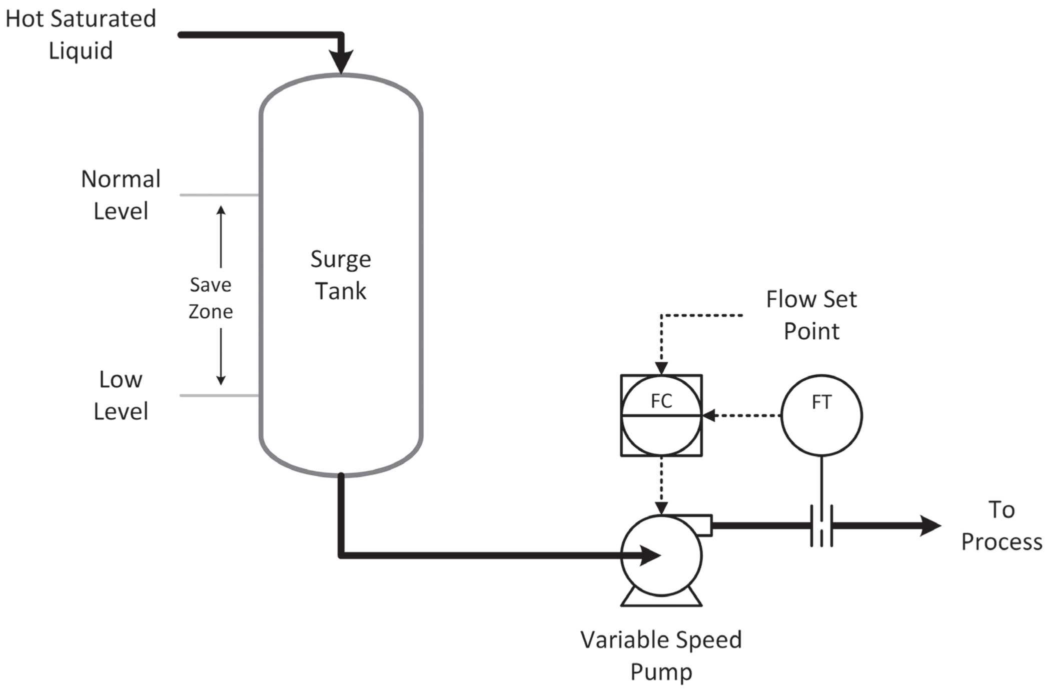


Figure 15-7. A system needing override control.

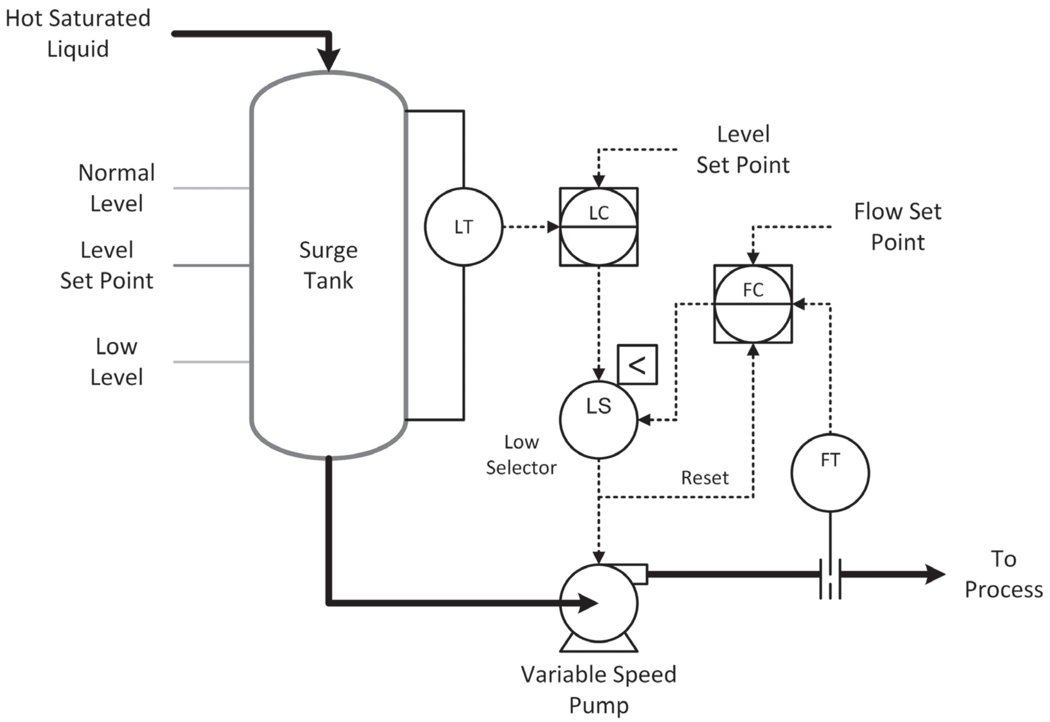


Figure 15-8. Override control system.

slows down and the level drops, the level controller will try to slow down the pump by reducing its output. When the output of the level controller drops below the output of the flow controller, the low-level selector relay will select the output of the level controller to control the pump. Now the level controller *overrides* the flow controller. Override control is also often called *constraint control* for this reason.

In override control, it is essential that any controller that has integral (reset) action must also have reset windup protection. This is shown in Figure 15-8 for the flow controller. The reset feedback structure prevents the integral action from saturating the controller when a changeover occurs. Reset windup in an override control system is a simple and straightforward way of preventing windup. Without such protection, the controller action is delayed until the controller reset action unwinds, and the override protection will most likely be too late. In the example shown, the flow controller will not wind up because of the reset feedback signal.

Distillation Column Example

As another example of override control, consider the distillation column differential pressure control shown in Figure 15-9. Temperature control is usually used to provide manipulation of steam flow to the reboiler. But if the column experiences downcomer flooding, it will greatly increase column differential pressure, and the steam flow rate must be reduced. The strategy shown in Figure 15-9 enables the temperature controller to set the reboiler steam flow rate as long as the column differential pressure is below its set point. This set point is the maximum desired differential pressure. In the example shown, both the temperature controller and the differential pressure controller are assumed to have the reset mode, both can be overridden, and thus both need reset windup protection. In this example, neither the temperature controller (TC) nor the differential pressure controller (PDC) will wind up because of the reset feedback signal. As long as one of the controllers is in control, the other controller is prevented from winding up.

Split-Range Control

In a split-range control strategy, a process parameter (e.g., temperature) is adjusted by more than one manipulated variable. A single controller’s output is connected to more than one final control element.

A common application for split-range control is when a temperature control loop must apply both heat and cooling to a process. This is normally accomplished by using two final control elements, one for heating and one for cooling. In industry, this is most often implemented using control valves equipped with positioners. Each valve operates through one-half of the controller’s output range, applying the maximum

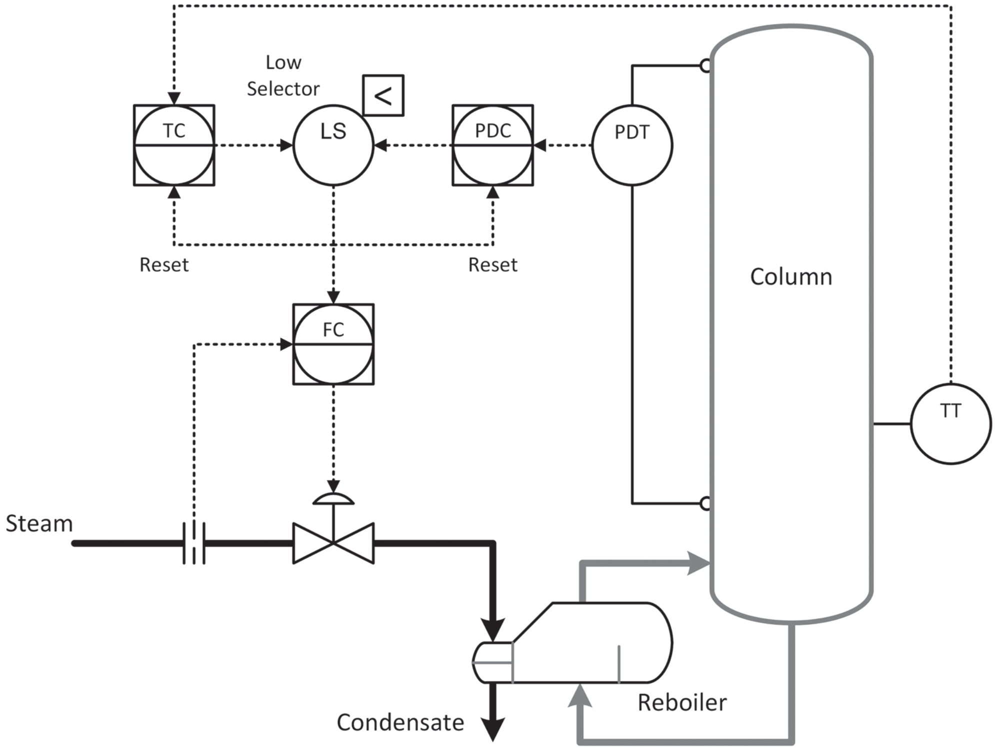


Figure 15-9. Column differential pressure override control.

heating or cooling at the extremes of the controller's output range. At the midpoint of the range, neither heating nor cooling is applied (see Figure 15-10).

Positioners are normally used, rather than relying on the valve-spring to realize the required ranges. Positioners will provide a more accurate and precise range splitting.

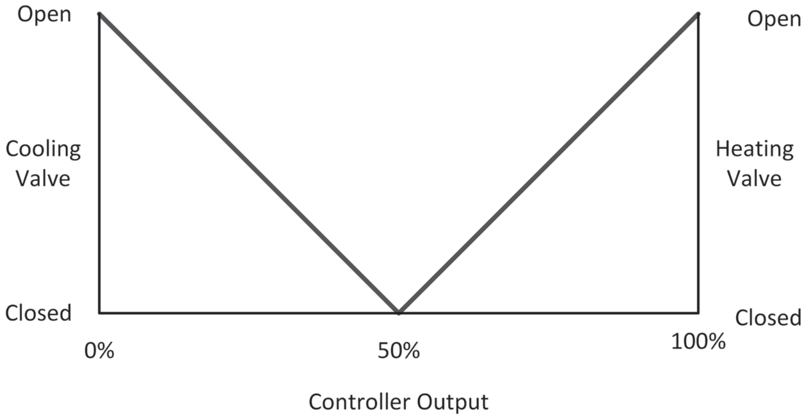


Figure 15-10. Valve positions versus controller output.

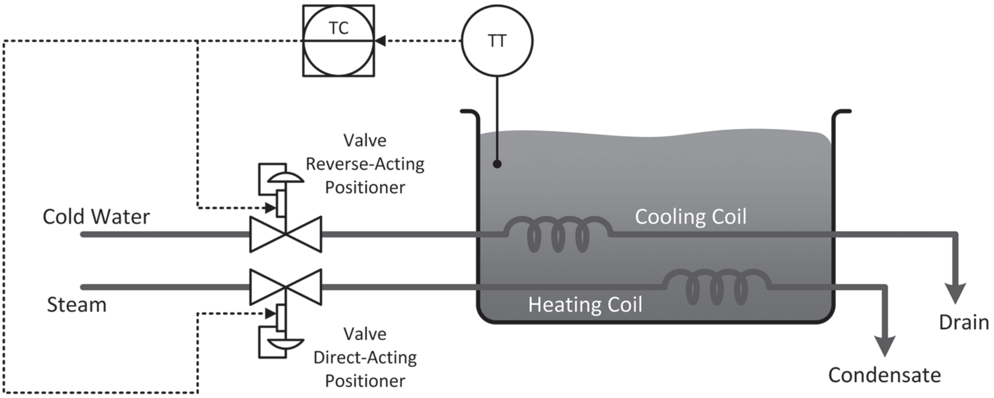


Figure 15-11. Split-range control of bath temperature.

The controller in split-range control has one input and two outputs. A typical example of the application of split-range control is shown in Figure 15-11. Assume that the temperature controller (TC) is a proportional-only controller; its output is fed to both control valves. Usually, the cold water valve signal varies from 0% to 100%, as is typical in split-range control; the valve action would be set so that the valve travels from full open to full close as input to the positioner changes from 0% to 50%. In addition, the steam valve would go from fully closed to fully open as the signal changes from 50% to 100% (see Figure 15-10). The system is designed so that the controller output produces a 50% signal when the measurement and set point agree, and, at this point, both valves are closed. If measured temperature rises above or falls below the set point, either water or steam will be circulated in proportion to the difference between the set point and the measured value of temperature.

Usually, for safety reasons, the cooling valve would operate from 0% to 50% and the steam valve would operate from 50% to 100%. This way, if a failure occurs and the controller output goes to zero, the system will then go to full cooling.

One problem with this setup is that the system may oscillate continuously between cooling and heating when the controller output is around 50%. To avoid this, a deadband between the two ranges can be added; an example of this would be setting a range of 0% to 49% for the cooling valve and a range of 51% to 100% for the heating valve. Alternatively, a small overlap can also be introduced so that at 50% both valves are slightly open; an example of this would be setting a range of 0% to 52% for the cooling valve and a range of 48% to 100% for the heating valve.

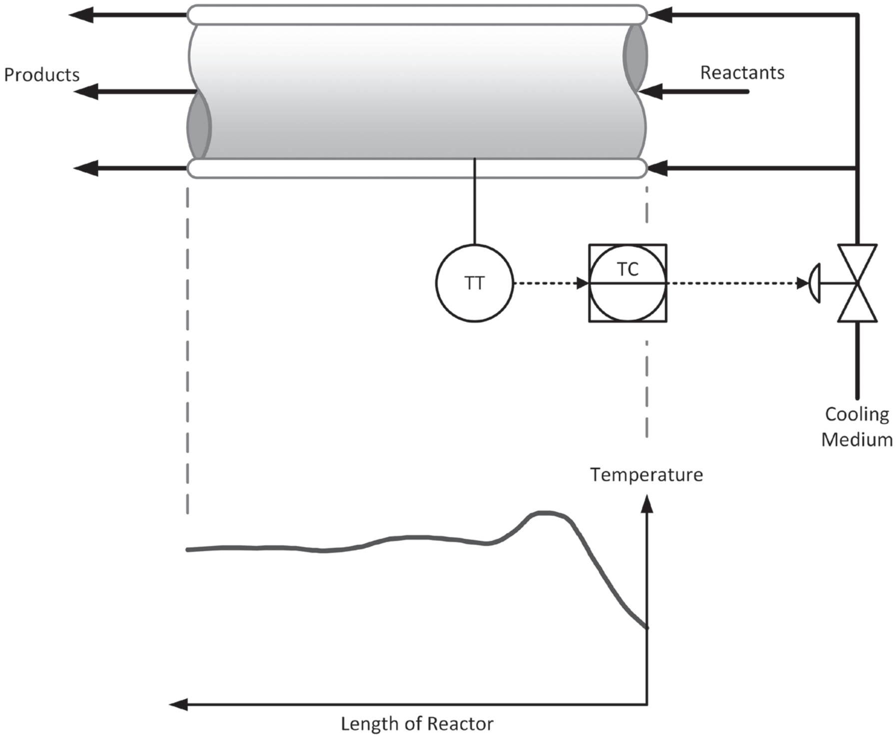
Split-range control is conceptually similar to selective control, as was shown in Figure 15-5, which also used a single controlled variable to constrain or choose between two manipulated variables.

15.4 Summary

Several advanced control strategies such as boiler control, selective control, override control, duplex control and split-range control were discussed. Each strategy was articulated with emphasis on the computational requirements involved.

Exercises

15.1 Consider the catalytic exothermic plug flow reactor, along with the typical temperature profile along the reactor, in the following figure.



As conditions change and as the catalyst ages, the hot spot moves. Design a selective control scheme so that the measured variable moves as the hot spot moves. Use multiple temperature measurements with a high selector.

15.2 To operate a pumping station on a pipeline efficiently, it is best to operate the control valve wide open on all stations but one. This station becomes the throttling unit. It is necessary to cut back on the control valve position if the:

- Suction pressure drops too low
- Motor load rises too high
- Discharge pressure rises too high

Sketch an auto-select/cutback control system to handle this.

ABOUT THE AUTHOR

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Patrick F. Bouwman is a semiretired electrical engineer with over 40 years of industrial experience, including 18 years in the design and development of military electronics, instrumentation, and biomedical equipment. For more than 15 years, Bouwman operated his own company specializing in research, design, and development of data acquisition and signal processing systems for medical research applications and the instrumentation and process industry. He has provided design and consulting services to the process and automation industry and participated in research conducted at McGill University by custom designing data acquisition equipment and instrumentation for medical research applications.

In addition, Bouwman taught industrial electronics at the collegiate level for over 20 years and was department chair for 16 years, a role in which he was actively involved in all facets of curriculum development, laboratory design, industrial training, and continuing education. He has written numerous instructional and lab manuals on topics including analog and digital electronics, signal processing, discrete automation, instrumentation, process control, PLC programming, ISA-5.1 technical documentation, robotics, computer automation, distributed automation, and medical and military electronics.

He has also provided technical training and instructional material to the Canadian Armed Forces; conducted seminars in data acquisition, signal processing, instrumentation, and control for the manufacturing industry; and prepared and conducted seminars/workgroups in instrumentation, process control, and ISA-5.1 for the International Society of Automation (ISA) Montreal Section.

Bouwman is a senior member of ISA, and he served on the Montreal Section board of directors. He received a B.Sc. in electrical and electronic engineering from Concordia University in Montreal in 1976, and he currently lives in Montreal, Canada.

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